Biophysics in Human Physiology
For 1st year medical students
2013

1- Compliance of :
- ✓ Lungs & chest wall
- ✓ CVS (heart, arteries, veins & delayed compliance)
- ✓ Urinary bladder
- ✓ Stomach

2- Starling law (length tension relationship) of :
- ✓ Skeletal muscle
- ✓ Heart

3- Blood flow

4- Poiseuille law

5- Laplace law

6- Starling forces for capillary fluid exchange

7- Nernst & Goldman equations to calculate RMP

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Compliance (elasticity)

- **Definition:** It is the change in volume per change in distending pressure.

$$C = \Delta V/\Delta P$$

✓ High compliance = high elasticity & distensibility
✓ Low compliance = stiffness

- **Elastance** is the tendency of elastic structure to recoil to its original dimension. It is the reciprocal of compliance.

$$E = \Delta P/\Delta V$$

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A. Compliance of Cardiovascular System

1- Compliance of the heart

- The heart is a hollow structure that can be distended.
- Increasing the blood volume inside the resting ventricle during diastole resulting in a rise of intra ventricular pressure.

▪ **The pressure –volume relationship has the following characters:**

- **At low volume**

The heart accommodates more blood with minimal increased in pressure i.e. ΔV/ΔP (compliance) is high. This is the portion of the curve at which ventricles work in a healthy person.

- **At higher volume**

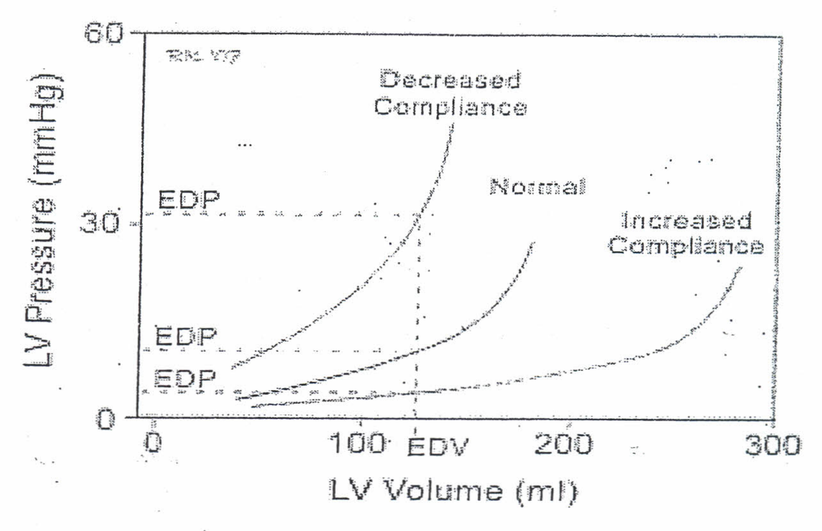
There is marked increased in ventricular pressure i.e. ΔV/ΔP (compliance) is low.

▪ **Effect of compliance on diastolic function of the ventricle**

- The ventricle is highly compliance during diastole so, any condition associated with decrease its ability to expand will decrease its compliance.
- Decrease compliance of the ventricle impaired its diastolic function → increase end diastolic pressure (EDP) and decrease end diastolic volume (EDV). In this case, the pressure-volume curve is shifted up and to the left.

- **Diastolic dysfunction occurs in the following diseases:**

- Concentric hypertrophy of the ventricle as in chronic hypertension or aortic stenosis.
- Thickening of the pericardium as in pericarditis
- Cardiac tamponade (pericardial effusion)
- Myocardial infarction



Ventricular pressure-volume curves

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2- Arterial compliance

Total systemic arterial compliance is mainly determined by the aorta and its major branches.

- **Arterial compliance serves the following functions:**

– Converts intermittent flow in the aorta to continuous flow in peripheral vessels. Recoil of the arteries during diastole keeps pushing blood forwards.

– Keep normal blood pressure by minimizes both the rise of SBP during systole and the decrease of DBP during diastole.

– Reduces cardiac work. Cardiac work is defined as pressure × volume. Therefore, for a given volume (COP), when compliance is low, the pressure is high and the work increases.

- **Factors control the arterial compliance**

1- Factors decrease arterial compliance

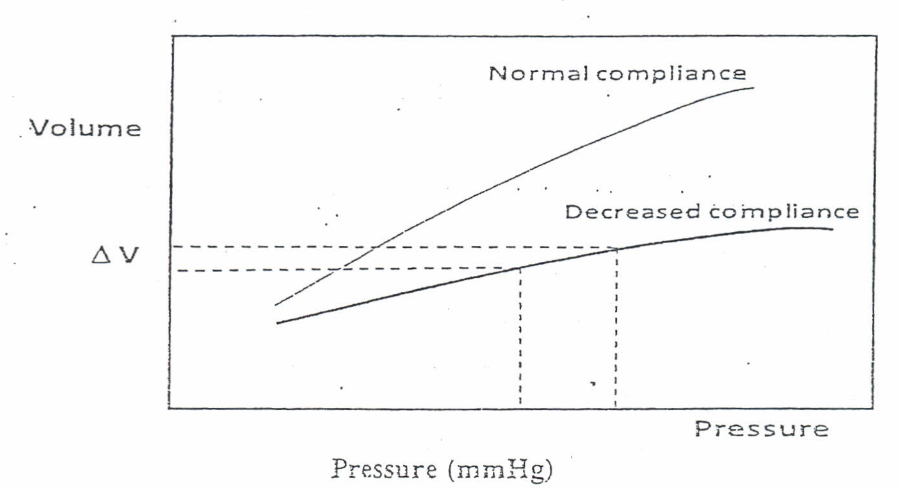
- Sympathetic activity: contraction of smooth muscle reduces their compliance
- Aging (loss of elastic fibers)
- Change components of vessel wall e.g. atherosclerosis
- Endothelial dysfunctions
- Hypertension
- Diabetes
- Smoking

2- Factors increase arterial compliance

- Hormones: estrogen increases vessel compliance
- Foods : fish oil
- Regular exercise: slow the normal loss of elasticity and compliance with aging.

The pressure volume relationship has the following characters:

- **With gradual increase in the blood volume**
- A linear relationship exist between volume & pressure i.e. ΔV/ΔP (compliance) is high. This is due to stretching of elastic fibers in arterial wall.
- As blood volume increases
- The curve becomes steeper. i.e. ΔV/ΔP (compliance) is low. This is because the elastic fibers have reached the upper limit of stretchibility & further increase in volume is only possible by stretching the very stiff collagen fibers.



Pressure (mmHg)

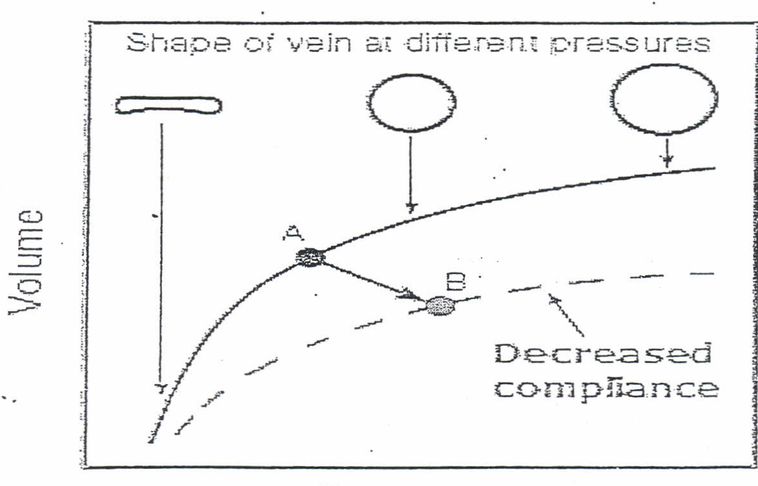
The pressure volume curves of arteries

3- Venous compliance

- **Large veins (e.g. vena cava) have the following criteria as compared to big arteries:**
  - Wide lumen & thin wall that is poor in elastic fibers.
  - Blood volume in veins is 3 times that in arteries.
  - Distensibility of veins is 8 times that of arteries.
  - Compliance of veins is about 24 times that of arteries. (C = volume x distensibility).
  - This means that large a mount of blood can be stored in the veins with slightly change in pressure. Therefore veins are the reservoir vessels & capacitance areas of the circulation.
  - Venous compliance is determined mainly by venous tone. Sympathetic stimulation increases venous tone and decreases compliance of vein → shifts the pressure –volume relationship down and to the right. In the opposite direction, decreasing venous tone e.g. vasodilator drug, will increase venous compliance and shifting the curve up and to the left.

- **At very low pressure and with increase in the blood volume**
  - ✓ It results in little change in pressure. i.e. $\Delta V/\Delta P$ (compliance) is very high. This is because veins are normally partially collapsed.
  - ✓ Pressure only changes the shape of the vein to become more cylindrical without actually stretching venous wall.

- At higher blood volumes
  - ✓ It results in marked rise in pressure. i.e. $\Delta V/\Delta P$ (compliance) is low.
  - ✓ Poor elasticity of the venous wall makes pressure stretches the venous wall.



The pressure volume curves of veins

4- Delayed compliance (stress relaxation) of blood vessels

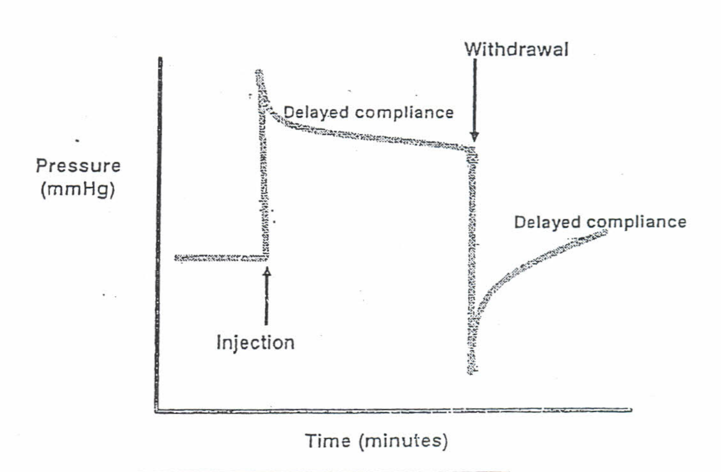
- **Definition:** it is the response of the blood vessels to a sudden change in the pressure or volume.
- It is related to viscoelastic properties of the smooth muscle and not related to the contractile properties.
- Delayed compliance occurs slightly in arteries but to a much greater extent in the veins.
- **If the pressure is being recorded in a small segment of a vein that is occluded at both ends:**

  - When extra volume of blood is suddenly injected into the segment, the pressure (stress) rose markedly at first, but progressively delayed stretching of smooth muscle allowed the pressure to go back toward original pressure over a period of minutes to hours.
  - When the extra blood volume was withdrawn the pressure suddenly fell to a very low value but after few minutes smooth muscle begins to readjust their tension and pressure slowly returned back to normal.

- **Clinical importance of delayed compliance**

The delayed compliance allows vessels to slowly adjust to an increase or decrease in blood volume without marked change in ABP

- ❑ Sudden increase in blood volume e.g. blood transfusion: initially, ABP is increased due to ++ MCFP & VR. Delayed compliance operates to decrease mean circulatory filling pressure (MCFP) which is finally minimize the change in ABP.
- ❑ Sudden decrease in blood volume as in hemorrhage or blood donation: the reverse occurs.



Delayed compliance curve

B- Compliance of the Urinary Bladder

Compliance is an important biomechanical parameter, characterizing the function of the bladder to store urine at low pressure. The intravesical pressure rises as the urinary bladder is filled with urine. The pressure-volume relationship has the following phases:

- Filling an empty bladder with 50ml → slight increase in pressure.
- Further increase in urine volume from 50-400→ little increase in pressure i.e. $\Delta V/\Delta P$ (compliance) is high.
- As volume rises above 400 ml → marked increase in pressure i.e. $\Delta V/\Delta P$ (compliance) is low, with strong desire for micturition.

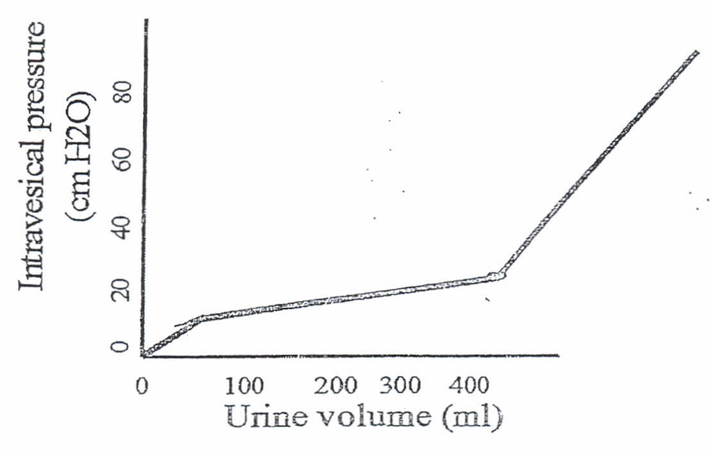
The compliance of the urinary bladder can be explained by:

1-***Plasticity* of the bladder**: increase in length without significant increase in pressure due to rearrangement of cross bridges between actin & myosin → decrease tension on cross bridges.

2- *Laplace law:* **P=2T/r** (P= pressure, T=tension, r=radius)

- As the bladder is filled, both the wall tension and the radius are increased so, pressure does not change significantly, with slight desire to micturate.
- Although the 1st desire for micturition is at 150 ml but the desire becomes strong as the volume exceeds 400ml.

This is due to marked increase in the wall tension but the radius is slightly increased. So the pressure is markedly increased.



Pressure-volume curve of urinary bladder

C- Compliance of the Stomach

Normally, body of the stomach can accommodate large quantities of food up to 1 L and the pressure remains low. i.e. $\Delta V/\Delta P$ (compliance) is high.

The compliance of the stomach can be explained by:

1-Plasticity **of the stomach**: increase in length without significant increase in pressure due to rearrangement of cross bridges between actin & myosin → decrease tension on cross bridges.

2- *Laplace law:* **P=2T/r** (P= pressure, T=tension, r=radius)
The radius is markedly increased as stomach filled with food.

3- **Reflex vagal inhibition** caused by stretch of stomach wall.

Good luck

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1. P wave represents.................................... , while QRS wave represent ....

2. P-R segment = ... sec, represents .... and is prolonged in ....

3. Plateau of ventricular action potential is represented by .... in ECG

4. Atrial repolarisation is .... while ventricular repolarisation is represented by ....

5. The normal ventricular electrical axis is between .... and ....; more than .... denotes ; and more than .... denotes ....

6. QRS amplitude in chest leads = ... and in limb leads = ...

7. S-T segment is........................

8. R-R interval represents ....

9. How could you calculate the heart rate using an ECG strip?

10. Q – wave is absent in ....

11. T – wave is inverted in ....

12. P – wave is inverted in ....

13. QRS is negative in .... and positive in ....
....

14. Interventricular septum is represented by .... wave in V1 while it is represented by ...... wave in V6

15. S- wave represents ....in V1 while it represents ....in V6

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1- Regarding the action potential of ventricular muscle

a. It lasts as long as the mechanical response
b. Rapid upstroke is due to inward Na^+ current I_{Na}
c. Upstroke terminates at +40mV
d. Plateau is due to inward Na^+ current & outward K^+ current

2- Regarding the plateau of cardiac muscles, all are true except

a. Maintained by a balance between inward Ca^{++} & outward k^+ currents
b. Terminal part is due to Na^+/Ca^{++} exchanger
c. It coincides with relative refractory period
d. It occurs around zero mV

3- Regarding the conductive system of the heart

a. Both SAN & AVN are innervated by the left vagus nerve
b. There is delay of about 0.1 second at AVN
c. Purkinje fibers have the shortest duration of action potential
d. The ventricular muscle has the fastest rate of conduction

4- Positive chronotropic effect of sympathetic stimulation is

a. Mediated through activation of B2-adrenergic receptors
b. Due to activation of L-type Ca++ channels
c. Blocked by cAMP
d. Due to rapid influx of Na+ increasing rapidity of funny current

5- The absolute refractory period of cardiac muscle

a. Coincides with total duration of action potential
b. During which the heart can respond to a maximal stimulus
c. Is longer than the refractory period of the skeletal muscle
d. Is the period during which delayed rectifier K channels are inactivate

1- Among the functions of surfactant:

a. Facilitation of lung expansion
b. Facilitation of lung collapse
c. Prevention of alveolar collapse during inspiration
d. Favors filtration of fluids from pulmonary capillaries into alveoli

2- Effects of unilateral pneumothorax include

a. Collapse of lung of opposite side
b. Lymph flow increases
c. Chest of same side expands
d. Venous return increases

3- Concerning the residual volume

a. Represents more than 30% of total lung capacity
b. It averages 2200 ml
c. It aerates blood between breathes
d. It equals the sum of tidal volume and expiratory reserve volume

4- Surfactant

a. Increases the surface tension of fluid lining the alveoli
b. Increases with inhalation of 100% Oxygen
c. Increases in premature babies
d. Becomes mature under effect of cortisol

5- With regards breathing

a. Inspiratory reserve volume equals maximum volume of air that can be inspired
b. The expanding pressure of lung equals intrapleural pressure – intraalveolar pressure
c. Residual volume equals volume of air remaining in lung following normal expiration
d. Expiratory reserve volume equals 1100 ml

1- <u>Regarding the cardiac muscle</u>

a. The more the initial the initial length of the muscle fibers, the more will be the force of contraction
b. The force of contraction decreases with repeated stimulation
c. Acidosis increases the contractility
d. Sympathetic stimulation produces negative inotropic effect

2- <u>The mechanisms that lower free sarcoplasmic Ca & produce relaxation of cardiac muscle are all except:</u>

a. Transport of Ca out of myocytes through Na-Ca exchanger
b. Active pump of Ca into SR by Ca-ATPase pump
c. Binding of Ca to tropomyosin
d. Transport of Ca out of myocytes through weak Ca-ATPase pump

3- <u>Inhibition of Ca influx into ventricular muscle cells during ventricular excitation results in</u>

a. Decrease in force of ventricular contraction
b. Increase in amount of Ca bound to troponin C during contraction
c. Increase in amount of Ca released from SR during contraction
d. Increase in overlap of myosin & actin during ventricular contraction

4- <u>Regarding cardiac muscle properties</u>

a. The strength of contraction depends on initial length of muscle fiber
b. Acetyl choline has a negative inotropic effect on ventricles
c. Adrenaline has a +ve inotropic effect
d. All of the above
e. a & c are correct

5- <u>Negative inotropic mechanisms include all except</u>

a. Ischemia of cardiac muscle
b. Calcium channel blockers
c. Inhibition of cAMP production
d. Inhibition of Na-K pump
e. Activation of muscarinic (M2) receptors